

DESCRIPTION

HOT DIP GALVANIZED COMPOSITE HIGH STRENGTH STEEL SHEET
EXCELLENT IN SHAPEABILITY AND HOLE ENLARGEMENT ABILITY
5 AND METHOD OF PRODUCTION OF SAME

TECHNICAL FIELD

The present invention relates to a hot dip
galvanized composite high strength steel sheet excellent
10 in shapeability and hole enlargement ability and a method
of production of the same.

BACKGROUND ART

In recent years, improved fuel economy of
automobiles and reduced weight of chasses have been
15 increasingly demanded. To reduce the weight, the need for
high strength steel sheet has been rising. However, along
with the rise in strength, this high strength steel sheet
has become difficult to shape. In particular, steel
materials have fallen in elongation. As opposed to this,
20 recently, TRIP steel (high residual austenite steel) high
in both strength and elongation has come to be used for
the frame members of automobiles.

However, conventional TRIP steel contains over 1% of
Si, so there were the problems that the plating is
25 difficult to uniformly stick and therefore the member to
which it can be applied are limited. Further, to maintain
a high strength in residual austenite steel, a large
amount of C has to be added. There were therefore
problems in welding such as nugget cracking. For this
30 reason, hot dip galvanized high strength steel sheet
reduced in the amount of Si has been proposed in Japan
Patent No. 2962038 and Japanese Patent Publication (A)
No. 2000-345288. However, with this art, while an
improvement in the platability and ductility can be
35 expected, no improvement in the above-mentioned
weldability can be expected. Further, with $TS \geq 980$ MPa
TRIP steel, the yield stress becomes extremely high, so

there was the problem of deterioration of the shape
freezability at the time of pressing etc. Therefore, to
solve the above problems in DP steel (composite structure
steel), the inventors previously proposed, in Japanese
5 Patent Application No. 2003-239040, art to set the Si,
Al, and TS balance in a specific range and enable the
industrial production of hot dip galvanized high strength
steel sheet enabling an elongation higher than ever
before in low yield stress DP steel to be secured.

10 Further, recently, there are also quite a few
members which are worked by burring to enlarge the worked
hole part and form a flange. Steel sheet also having a
hole enlargement ability as an important characteristic
is therefore starting to be demanded. In respect to this
15 demand, in the ferrite+martensite DP steel proposed in
the above-mentioned Patent Document 2, since the
difference in strength between the martensite and ferrite
is large, there is the problem that the hole enlargement
ability is inferior.

20 DISCLOSURE OF THE INVENTION

The present invention has as its object to resolve
the above-mentioned conventional problems and realize a
hot dip galvanized composite high strength steel sheet
excellent in shapeability and hole enlargement ability
25 and a method of production of the same on an industrial
scale.

The inventors engaged in intensive studies on hot
dip galvanized composite high strength steel sheet
excellent in shapeability, plating adhesion, and hole
30 enlargement ability and a method of production of the
same and as a result discovered that by optimizing the
steel ingredients, that is, reducing the amount of Si and
using Al as an alternative element, it is possible to
improve the adhesion of hot dip galvanization, that by
35 specifying the relationship between Si and Al and
limiting the amounts of addition of C and Mn, it is
possible to give superior features of both strength and

elongation, and that by applying the necessary heat treatment after the hot dip galvanization step, a material stable in hole enlargement ability and embrittlement can be obtained. The inventors discovered that in steel sheet designed based on this technical idea, by making low yield stress DP steel a metal structure mainly comprised of ferrite in accordance with the conventional residual austenite steel and tempered martensite with an area rate of 5% to 60%, it is possible to secure an elongation greater than before and obtain a DP structure excellent in hole enlargement ability and optimal for hot dip galvanization.

Further, in the present invention, to prevent delayed fracture and secondary embrittlement or other problems from occurring, the unavoidably included 5% or less residual austenite may be allowed. The present invention is based on the above technical idea and has as its gist the following:

(1) A hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability characterized by containing, by mass%, C: 0.01 to 0.3%, Si: 0.005 to 0.6%, Mn: 0.1 to 3.3%, P: 0.001 to 0.06%, S: 0.001 to 0.01%, Al: 0.01 to 1.8%, and N: 0.0005 to 0.01% and having a balance of Fe and unavoidable impurities, wherein the metal structure is comprised of ferrite and, by area ratio, 5% to 60% of tempered martensite.

(2) A hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in (1), characterized in that said hot dip galvanized composite high strength steel sheet further contains, by mass%, one or more of Mo: 0.05 to 0.5%, V: 0.01 to 0.1%, Ti: 0.01 to 0.2%, Nb: 0.005 to 0.05%, Cu: 1.0% or less, Ni: 1.0% or less, Cr: 1.0% or less, Ca: 0.0003 to 0.005%, REM: 0.0003 to 0.005%, and B: 0.0003 to 0.002%.

(3) A hot dip galvanized composite high strength

steel sheet excellent in shapeability and hole enlargement ability as set forth in (1) or (2), characterized in that said hot dip galvanized composite high strength steel sheet further contains Al, by mass%, of 0.25 to 1.8% in range and in that the mass% of Si and Al and the target tensile strength (TS) satisfy the following equation 1:

$$(0.0012 \times [\text{TS target value}] - 0.29 - [\text{Si}]) / 1.45 < \text{Al} < 1.5 - 3 \times [\text{Si}] \dots \text{equation 1}$$

[TS target value]: Design value of tensile strength of steel sheet (MPa), [Si]: Si mass%, Al: Al mass%

(4) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability characterized by hot rolling, then cold rolling a slab containing, by mass%, C: 0.01 to 0.3%, Si: 0.005 to 0.6%, Mn: 0.1 to 3.3%, P: 0.001 to 0.06%, S: 0.001 to 0.01%, Al: 0.01 to 1.8%, and N: 0.0005 to 0.01% and having a balance of Fe and unavoidable impurities, heating the sheet in a hot dip galvanization heating step to A_{c1} to $A_{c3} + 100^\circ\text{C}$ in temperature, holding it there for 30 seconds to 30 minutes, then cooling it by a 1°C/s or higher cooling rate to 450 to 600°C in temperature, then hot dip galvanizing it at that temperature, then cooling it by a 1°C/s or higher cooling rate to the martensite transformation point or less in temperature, then holding it at 200°C to 500°C in temperature for 1 second to 5 minutes, then cooling it by a 5°C/s or higher cooling rate to 100°C or less so as to obtain a metal structure comprised of ferrite and of tempered martensite of an area rate of 5% to 60%.

(5) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in (4), characterized by performing alloying after said hot

dip galvanization.

(6) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in (4) or (5), characterized by said further treating a galvanized layer or galvanized layer by one or more of a chromate treatment, inorganic coating film treatment, chemical conversion, or resin coating film treatment.

(7) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in any one of (4) to (6), characterized in that said hot dip galvanized composite high strength steel sheet further contains, by mass%, one or more of Mo: 0.05 to 0.5%, V: 0.01 to 0.1%, Ti: 0.01 to 0.2%, Nb: 0.005 to 0.05%, Cu: 1.0% or less, Ni: 1.0% or less, Cr: 1.0% or less, Ca: 0.0003 to 0.005%, REM: 0.0003 to 0.005%, and B: 0.0003 to 0.002%.

(8) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in any one of (4) to (7), characterized in that said hot dip galvanized composite high strength steel sheet further contains Al, by mass%, in 0.25 to 1.8% in range and in that the mass% of Si and Al and a target tensile strength (TS) satisfy the following equation 1:

$$(0.0012 \times [\text{TS target value}] - 0.29 - [\text{Si}]) / 1.45 < \text{Al} < 1.5 - 3 \times [\text{Si}] \dots \text{equation 1}$$

[TS target value]: Design value of tensile strength of steel sheet (MPa), [Si]: Si mass%, Al: Al mass%

(9) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in any one of (4) to (8), characterized by, from said cold rolling to the hot dip galvanization heating step, preplating one or more of Ni, Fe, Co, Sn, and Cu to 0.01

to 2.0 g/m² per surface of the steel sheet.

(10) A method of production of a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability as set forth in (9), characterized by pickling the steel sheet before said preplating.

BEST MODE FOR WORKING THE INVENTION

First, the reasons for limitation of the ingredients and metal structure of the hot dip galvanized composite high strength steel sheet prescribed in the present invention will be explained.

C is an essential ingredient as a basic element for securing strength and stabilizing the martensite structure. If C is less than 0.01%, the strength cannot be secured and no martensite phase will be formed. On the other hand, if over 0.3%, the strength will rise too much, the ductility will become insufficient, and the weldability will deteriorate. Therefore, the range of C is 0.01 to 0.3%, preferably 0.03 to 0.15%.

Si is an element added for securing strength and ductility, but if over 0.6%, the hot dip galvanization ability deteriorates. Therefore, the range of Si is made 0.005 to 0.6%. Further, when stressing the hot dip galvanization ability, not more than 0.1% is more preferable.

Mn is an element which has to be added from the viewpoint of securing the strength and in addition delays the formation of carbides and is an element required for the formation of austenite. If Mn is less than 0.1%, the strength is not satisfactory. Further, with addition over 3.3%, the martensite increases too much and invites a rise in strength, the variation in strength increases, and the ductility is insufficient, so use as an industrial material is not possible. For this reason, the range of Mn was made 0.1 to 3.3%.

P is added in accordance with the level of strength required as an element raising the strength of the steel

sheet, but if the amount of addition is large, it segregates at the grain boundary, so degrades the local ductility and simultaneously degrades the weldability, so the upper limit value of P was made 0.06%. On the other
5 hand, the lower limit of P was made 0.001% to avoid an increase in cost of refining.

Further, S is an element forming MnS and thereby degrading the local ductility and the weldability. It is an element preferably not present in the steel, so the
10 upper limit value was made 0.01%. The lower limit was made 0.001% to avoid an increase in cost of refining.

Al is an element required for promoting the formation of ferrite and is effective in improving the ductility. Even if a large amount is added added, it does
15 not inhibit the hot dip galvanizability. Further, it acts as a deoxidizing element. Therefore, from the viewpoint of improving the ductility, Al has to be included in an amount of 0.01% or more, but even if Al is excessively added, its effect becomes saturated and conversely the
20 steel becomes embrittled. Simultaneously, the hot dip galvanization ability is reduced. Therefore, the upper limit was made 1.8%. From the viewpoint of securing the steel sheet strength, addition of 0.25% to 1.8% is preferable.

25 N is an unavoidably included element, but when included in a large amount, not only is the aging effect deteriorated, but also the amount of deposition of AlN becomes greater and the effect of addition of Al is reduced, so 0.01% or less is preferably contained.
30 Further, unnecessarily reducing the N increases the cost in the steel making process, so normally the amount of N is controlled to 0.0005% or more.

In the present invention, when further higher strength is required, to improve the plating adhesion, if
35 adding a large amount of Al instead of Si, in particular when $0.25\% \leq Al \leq 1.8\%$, by making the balance of Al and Si with TS the following equation 1 in range, sufficient

ferrite can be secured and both a greater hot dip galvanization ability and ductility can be secured.

$$(0.0012 \times [\text{TS target value}] - 0.29 - [\text{Si}]) / 1.45 < \text{Al} < 1.5 - 3 \times [\text{Si}] \dots \text{equation 1}$$

5 Here, in the above equation 1, [TS target value] means the design value of the tensile strength of the steel sheet (MPa), [Si] means the Si mass%, and Al means the Al mass%.

10 Further, in the present invention, in addition to the above ingredients, it is further possible to add one or more of Mo: 0.05 to 0.5%, V: 0.01 to 0.1%, Ti: 0.01 to 0.2%, Nb: 0.005 to 0.05%, Cu: 1% or less, Ni: 1% or less, Cr: 1% or less, Ca: 0.003 to 0.005%, REM: 0.0003 to 0.005%, and B: 0.0003 to 0.002%.

15 Mo has an effect on the steel sheet strength and hardenability. If less than 0.05%, the effect of hardenability distinctive to Mo cannot be exhibited, sufficient martensite will not be formed, and the strength will be insufficient. On the other hand, 20 addition of 0.5% or more suppresses ferrite formation and degrades the ductility and simultaneously also degrades the plateability, so 0.5% was made the upper limit.

25 V, Ti, and Nb can be added for improvement of strength in ranges of V: 0.01 to 0.1%, Ti: 0.01 to 0.2%, and Nb: 0.005 to 0.05%. Further, Cr, Ni, and Cu may also be added as strengthening elements, but if 1% or more, the ductility and chemical convertability deteriorate. Further, Ca and a REM can improve the inclusion control and hole enlargement ability, so Ca: 0.0003 to 0.005% and 30 REM: 0.0003 to 0.005% in range may be added. Further, B increases the hardenability and effective Al due to BN deposition, so B: 0.0003 to 0.002% can be added.

35 In the present invention, the structure of the steel sheet is made a composite structure of ferrite and martensite so as to obtain a steel sheet excellent in the strength and ductility balance. The "ferrite" indicates polygonal ferrite and bainitic ferrite. Note that the

cooling after annealing may cause partial formation of bainite. Note that if austenite remains, the secondary work embrittlement and delayed fracture properties deteriorate, so while an unavoidably residual rate of deposition of 5% or less of residual austenite is allowed, it is preferred that substantially no residual austenite be included.

Further, in the present invention, the biggest feature in the metal structure of the hot dip galvanized composite high strength steel sheet is that the steel contains, by area rate, 5% to 60% of tempered martensite. This tempered martensite is the tempered martensite structure resulting from the martensite produced in the cooling process after the hot dip galvanization being cooled to the martensite transformation point or less, then being tempered by heat treatment at 200 to 500°C. Here, if the area rate of the tempered martensite is less than 5%, the hardness difference between structures becomes too large and no improvement in the hole enlargement rate is seen, while if over 60%, the steel sheet strength drops too much, so the area rate of the tempered martensite was made 5% to 60%. Further, the residual austenite is made 5% or less to prevent the problems of delayed fracture and secondary work embrittlement. This substantially results in ferrite, martensite, and a tempered martensite structure forming the main phase. The balanced presence of these in the steel sheet is believed to cause the workability and hole enlargement rate to be improved. Note that the sheet is cooled to the martensite transformation point temperature or less after the hot dip galvanization, then is heated and tempered because if performed before the plating, the plating step will then result in further tempering and the desired amount of tempered martensite will not be obtained.

Next, the method of production of a hot dip galvanized composite high strength steel sheet according

to the present invention will be explained. The base material of the hot dip galvanized composite high strength steel sheet according to the present invention is a slab containing the above steel ingredients which is hot rolled by the usual process to produce hot rolled steel sheet which in turn is pickled, cold rolled, then run through a continuous hot dip galvanization line. In the heating process, the sheet is annealed at a temperature range of Ac_1 to $Ac_3+100^\circ C$. In this case, with an annealing temperature of less than the Ac_1 in temperature, the structure of the steel sheet would become nonhomogeneous, while if over $Ac_3+100^\circ C$ in temperature, the austenite would become coarser, formation of ferrite would be suppressed, and the ductility would drop. From the economic viewpoint, the upper limit temperature is preferably $900^\circ C$ or less. Further, the holding time in the annealing is preferably 30 seconds to 30 minutes in order to separate the layered structure. With over 30 seconds in holding time, the effect is saturated and the productivity falls. The thus annealed steel sheet is then cooled. At the time of cooling, the sheet is cooled by a $1^\circ C/s$ or higher, preferably a $20^\circ C/s$ or higher cooling rate to 450 to $600^\circ C$. With a cooling temperature over $600^\circ C$, austenite would easily remain in the steel sheet and the secondary workability and delayed fracture property would deteriorate. On the other hand, if less than $450^\circ C$, the temperature would become too low for the subsequent hot dip galvanization and the plating would be obstructed. Note that the cooling rate is made $1^\circ C/s$ or more, preferably $20^\circ C/s$ or more.

The thus annealed and cooled steel sheet may, during the hot dip galvanization, also be held at 300 to $500^\circ C$ in temperature for 60 seconds to 20 minutes as overaging treatment. This overaging treatment is preferably not

applied, but overaging treatment of the above-mentioned extent of conditions has no great effect on the material quality.

5 The thus treated steel sheet is then hot dip
galvanized. This plating may be performed under the
usually practiced plating conditions. The temperature of
the hot dip galvanization bath may be one used in the
past. For example, a condition of 440 to 500°C may be
applied. Further, so long as the hot dip metal is mainly
10 comprised of zinc, it may also contain unavoidable
elements such as Pb, Cd, Ni, Fe, Al, Ti, Nb, Mn, etc.
Further, to improve the quality of the plating layer
etc., the plating layer may also contain predetermined
amounts of Mg, Ti, Mn, Fe, Ni, Co, and Al. Further, by
15 making the amount of the hot dip galvanization 30 to 200
g/m² per side of the steel sheet, use for various
applications becomes possible. Note that in the present
invention, after the above hot dip galvanization, it is
also possible to perform alloying to obtain a hot dip
20 galvanized steel sheet. In this case, as the alloying
conditions, use of 470 to 600°C enables a suitable
concentration of Fe in the hot dip galvanized layer.
For example, the Fe can be controlled to, by mass%, 7 to
15%.

25 After the hot dip galvanization or after the hot dip
galvanization, the steel sheet is cooled to the
martensite transformation point temperature or less to
cause a martensite structure to be formed in the steel
sheet. The martensite transformation point M_s is found by
30 $M_s (^{\circ}\text{C}) = 561 - 471 \times \text{C}(\%) - 33 \times \text{Mn}(\%) - 17 \times \text{Ni}(\%) - 17 \times \text{Cr}(\%) - 21 \times \text{Mo}(\%)$,
but at $M_s (^{\circ}\text{C})$ or more, no martensite is formed. Further,
the cooling rate in the cooling is preferably 1°C/s or
more. To reliably obtain a martensite structure, a 3°C/s
or higher cooling rate is preferable.

35 The thus treated steel sheet is then held at 200°C to
500°C in temperature for 1 second to 5 minutes, then is

cooled at a 5°C/s or higher cooling rate to 100°C or less in temperature. In this heat treatment, at less than 200°C in temperature, tempering does not occur, the difference in hardness between structures becomes great, and no improvement in the hole enlargement rate can be observed, while if over 500°C, the sheet is overly tempered and the strength falls. This heating process is connected to the continuous hot dip galvanization line. It is also possible to provide this at a separate line, but a line connected to the continuous hot dip galvanization line is preferable from the viewpoint of the productivity. Further, if said holding time is less than 1 second, there is almost no progress in tempering or the tempering becomes incomplete and no improvement in the hole enlargement rate can be observed. Further, if over 5 minutes, the tempering is almost completely finished, so the effect becomes saturated with over that time. Further, the cooling after the heating is performed by a cooling rate of 5°C/s or more, preferably 15°C/s or more, in order to maintain a predetermined amount of tempered martensite.

Note that in the present invention, to improve the corrosion resistance, the hot dip galvanized steel sheet or hot dip galvanized steel sheet produced by the above process may be treated on its surface by one or more of chromate treatment, inorganic coating film treatment, conversion treatment, and resin coating film treatment.

Further, in the present invention, during the period from after the cold rolling to the hot dip galvanization heating step, one or more of Ni, Fe, Co, Sn, and Cu is preferably preplated to 0.01 to 2.0 g/m², preferably 0.1 to 1.0 g/m², per side of the steel sheet. As the method of preplating, any of the methods of electroplating, dipping, and spray plating may be employed. If the amount of plating deposition is less than 0.01 g/m², the effect of improvement of adhesion by the plating is not

obtained, while if over 2.0 g/m^2 , the cost rises, so the amount was made 0.01 to 2.0 g/m^2 per side of the steel sheet. Note that the sheet may be pickled before the above preplating. This pickling activates the surface of the steel sheet and can improve the plating adhesion of the preplating. Further, performing pickling in the continuous annealing process so as to remove the Si, Mn, and other oxides formed on the surface of the steel sheet is also an effective means for improving the plating adhesion. The pickling may be performed using hydrochloric acid, sulfuric acid, or other acids used in the past. For example, pickling conditions of a 2 to 20% pickling solution concentration and a 20 to 90°C temperature may be used. Further, dipping, electrolysis, spraying, or another pickling method tailored to the facility may be used. The pickling time depends on the acid concentration as well, but preferably is 1 to 20 seconds.

Further, to improve the plating adhesion, it is preferable to form an internal oxide layer or grain boundary oxides near the surface of the steel sheet before plating so as to prevent concentration of Mn or Si at the surface or to grind the surface by a grinding brush by a cleaning facility at the entry side to the hot dip galvanization heating process.

Example 1

Steel slabs obtained by melting and casting steel having the compositions of ingredients shown in Table 1 in a vacuum melting furnace were reheated at 1200°C , then hot rolled at a temperature of 880°C and finally rolled to produce hot rolled steel sheets. These were then cooled, coiled at a coiling temperature of 600°C , and held at that temperature for 1 hour to reproduce coiling heat treatment of hot rolling. The obtained hot rolled steel sheets were ground to remove the scale, cold rolled by a 70% reduction rate, then heated to a temperature of 800°C

using a continuous annealing simulator, heated to a temperature of 800°C, then held at that temperature for 100 seconds for continuous annealing. Next, the sheets were cooled by 5°C/s to 650°C, then were hot dip galvanized at 460°C and alloyed at a temperature of 520°C. Next, they were processed by two methods of production, that is, the conventional method and the invention method, to produce galvanized steel sheets.

(1) Conventional method: After this, cooling at 10°C/s to ordinary temperature.

(2) Invention example: After this, cooling at 10°C/s to martensite transformation point or less, then heating at 300°C in temperature for 60 seconds, then cooling at 20°C/s cooling rate to 100°C or less.

The results are shown in Table 2 and Table 3.

Note that the tensile strength (TS), hole enlargement rate, metal structure, plating adhesion, plating appearance, and judgment of passage shown in Table 2 and Table 3 were as follows:

• Tensile strength: Evaluated by L-direction tension of JIS No. 5 tensile test piece.

• Hole enlargement rate: The hole enlargement test method of Japan Iron and Steel Federation standard, JFS T1001-1996 was employed. A 10 mmφ punched hole (die inside diameter of 10.3 mm, clearance of 12.5%) was enlarged by a 60° vertex conical punch in the direction with the burr of the punched hole at the outside at a rate of 20 mm/min.

Hole enlargement rate: λ (%) = $\{D - D_0\} \times 100$

D: Hole diameter when crack passes through sheet thickness (mm)

D₀: Initial hole diameter (mm)

• Metal structure: Observed under optical microscope and, for ferrite, observed by Nital etching and, for martensite, by repeller etching.

The area ratio of tempered martensite was quantized by polishing a sample by repeller etching (alumina finish), immersing it in a corrosive solution (mixed solution of pure water, sodium pyrophosphite, ethyl alcohol, and picric acid) for 10 seconds, then again polishing it, rinsing it, then drying the sample by cold air. The structure of the dried sample was observed under a magnification of 1000X and a 100 μm x 100 μm area was measured by a Luzex apparatus to determine the area% of the tempered martensite. Table 2 and Table 3 show the area percent of this tempered martensite as the "tempered martensite area%".

• Plating adhesion: Evaluated from state of plating peeling of bent part in 60°V bending test.

15 Very good: Small plating peeling (peeling width less than 3 mm)

 Good: Light peeling of extent not posing practical problem (peeling width of 3 mm to less than 7 mm)

20 Fair: Considerable amount of peeling observed (peeling width of 7 mm to less than 10 mm)

 Poor: Extreme peeling (peeling width of 10 mm or more)

 A plating adhesion of "very good" or "good" was deemed passing.

25 • Plating appearance: Visual observation

 Very good: No nonplating or unevenness, even appearance

 Good: No nonplating, uneven appearance of extent not posing practical problem

30 Fair: Remarkable uneven appearance

 Poor: Nonplating and remarkable uneven appearance

 A plating appearance of "very good" or "good" was deemed passing.

 • Passing: $\text{TS} \geq 540 \text{ MPa}$, $\text{TS} \times \text{El} \geq 18,000$

35 Hole enlargement rate: $\text{TS} < 980 \text{ MPa}$... 50% or more considered passing

TS≥980 MPa... 40% or more considered passing

Table 1/Ingredients

Steel type	TS target	C	Si	Mn	P	S	N	Al	Mo	V
A	400	0.032	0.102	1.96	0.022	0.004	0.0050	0.033		
B	400	0.048	0.081	2.21	0.012	0.003	0.0060	0.050		
C	480	0.018	0.176	1.31	0.032	0.005	0.0070	0.810		
D	500	0.018	0.112	2.35	0.043	0.006	0.0100	0.990		
E	540	0.027	0.074	2.87	0.016	0.003	0.0050	0.430		
F	550	0.030	0.177	1.11	0.016	0.009	0.0050	0.950		
G	560	0.032	0.186	2.78	0.029	0.006	0.0030	0.930		
H	570	0.044	0.100	2.34	0.039	0.002	0.0080	0.300		
I	580	0.058	0.171	2.06	0.056	0.007	0.0030	0.970		
J	580	0.058	0.160	0.17	0.033	0.002	0.0080	0.900	0.180	
K	590	0.071	0.196	1.42	0.037	0.003	0.0050	0.550		
L	640	0.082	0.089	1.15	0.016	0.004	0.0050	1.140		
M	680	0.082	0.081	2.93	0.040	0.001	0.0030	1.050		
N	700	0.093	0.055	1.84	0.007	0.006	0.0070	0.500		
O	760	0.100	0.013	0.70	0.002	0.080	0.0040	0.810		
P	780	0.110	0.122	2.64	0.057	0.009	0.0020	0.730		
Q	800	0.120	0.084	0.17	0.010	0.010	0.0040	0.870		
R	840	0.120	0.148	0.19	0.016	0.008	0.0060	1.000		
S	900	0.134	0.047	0.19	0.042	0.010	0.0070	1.110		
T	920	0.140	0.042	1.71	0.021	0.006	0.0050	0.780		
U	950	0.144	0.076	0.89	0.033	0.011	0.0060	0.580	0.190	
V	950	0.142	0.116	0.27	0.046	0.007	0.0060	0.850	0.250	
W	980	0.147	0.122	0.92	0.035	0.009	0.0070	0.680	0.270	
X	980	0.150	0.107	1.76	0.059	0.006	0.0090	0.880		
Y	1280	0.210	0.153	1.20	0.025	0.005	0.0020	0.780		
Z	1320	0.235	0.176	2.73	0.051	0.008	0.0040	0.850		
AA	950	0.122	0.275	0.27	0.046	0.007	0.0060	0.650		
AB	1180	0.152	0.118	1.95	0.055	0.008	0.0090	0.720	0.280	
AC	1180	0.150	0.107	2.99	0.059	0.006	0.0090	0.880		
AD	1200	0.210	0.299	1.20	0.025	0.005	0.0020	0.600		0.050
AE	1350	0.250	0.233	1.36	0.039	0.009	0.0080	0.750	0.270	
AF	1480	0.289	0.186	2.06	0.052	0.004	0.0080	0.910		
AG	780	0.095	0.247	2.09	0.008	0.007	0.0029	0.892		
AH	780	0.101	0.226	2.68	0.006	0.008	0.0080	1.712		
AI	1130	0.261	0.276	0.43	0.043	0.009	0.0090	0.815		0.050
AJ	1470	0.300	0.289	0.47	0.038	0.005	0.0005	1.391		
AK	1570	0.295	0.395	0.52	0.040	0.004	0.0032	0.212	0.150	
AL	1570	0.298	0.526	0.88	0.049	0.006	0.0069	0.106		
AM	310	0.009	0.202	0.43	0.007	0.010	0.0063	1.778		
AN	1570	0.320	0.113	2.92	0.003	0.006	0.0007	0.462		
AO	980	0.166	0.607	2.64	0.056	0.009	0.0049	0.422		0.050
AP	880	0.113	0.083	0.09	0.049	0.001	0.0006	0.527		
AQ	1180	0.164	0.285	3.44	0.020	0.004	0.0041	1.247	0.072	
AR	780	0.125	0.267	2.06	0.070	0.003	0.0009	0.337		
AS	540	0.058	0.131	2.50	0.002	0.020	0.0059	0.377		
AT	540	0.026	0.145	0.15	0.011	0.010	0.0200	0.273		
AU	720	0.099	0.188	0.45	0.046	0.002	0.0030	0.009		
AV	880	0.130	0.186	2.39	0.051	0.006	0.0030	2.010		

Table 1 (continued)

[illegible]

Table 2/Method of Production (1)

Exper. no.	Steel type	TS (MPa)	EL (%)	TSxEL	(A) equation				(A) equation judgment
					TS target value (MPa)	(A) equation left side	Al	(A) equation right side	
1	A	409	44.1	18037	400	0.061	0.033	1.194	Poor
2	B	417	43.9	18306	400	0.075	0.050	1.257	Poor
3	C	476	37.9	18040	480	0.076	0.810	0.972	Good
4	D	508	36.9	18745	500	0.137	0.990	1.164	Good
5	E	551	33.0	18183	540	0.196	0.430	1.278	Good
6	F	549	33.1	18172	550	0.133	0.950	0.969	Good
7	G	568	32.5	18460	560	0.135	0.930	0.942	Good
8	H	582	31.9	18566	570	0.203	0.300	1.200	Good
9	I	591	30.9	18262	580	0.162	0.970	0.987	Good
10	J	584	31.2	18221	580	0.170	0.900	1.020	Good
11	K	605	29.9	18090	590	0.153	0.550	0.912	Good
12	L	632	30.1	19023	640	0.268	1.140	1.233	Good
13	M	688	28.7	19746	680	0.307	1.050	1.257	Good
14	N	695	27.2	18904	700	0.341	0.500	1.335	Good
15	O	743	24.8	18426	760	0.420	0.810	1.461	Good
16	P	812	23.2	18838	780	0.361	0.730	1.134	Good
17	Q	825	22.8	18810	800	0.404	0.870	1.248	Good
18	R	852	21.5	18318	840	0.393	1.000	1.056	Good
19	S	905	20.1	18191	900	0.512	1.110	1.359	Good
20	T	899	20.5	18430	920	0.532	0.780	1.374	Good
21	U	952	19.0	18088	950	0.534	0.580	1.272	Good
22	V	934	19.5	18213	950	0.506	0.850	1.152	Good
23	W	987	19.1	18852	980	0.527	0.680	1.134	Good
24	X	1024	18.2	18637	980	0.537	0.880	1.179	Good
25	Y	1320	14.9	19668	1280	0.754	0.780	1.041	Good
26	Z	1400	13.5	18900	1320	0.771	0.850	0.972	Good
27	AA	965	19.9	19204	950	0.397	0.650	0.675	Good
28	AB	1206	15.2	18331	1180	0.695	0.720	1.146	Good
29	AC	1230	15.8	19434	1180	0.703	0.880	1.179	Good
30	AD	1220	15.3	18666	1200	0.587	0.600	0.603	Good
31	AE	1364	13.4	18278	1350	0.757	0.750	0.801	Poor
32	AF	1520	12.2	18544	1480	0.897	0.910	0.942	Good
33	AG	795	22.5	17888	780	0.275	0.892	0.759	Poor
34	AH	825	20.9	17243	780	0.290	1.712	0.822	Poor
35	AI	1158	15.1	17486	1130	0.545	0.815	0.672	Poor
36	AJ	1476	12.2	18007	1470	0.817	1.391	0.633	Poor
37	AK	1584	11.4	18058	1570	0.827	0.212	0.315	Poor
38	AL	1603	11.3	18114	1570	0.737	0.106	-0.078	Poor
39	AM	335	33.2	11122	310	-0.083	1.778	0.894	Poor
40	AN	1623	7.8	12659	1570	1.021	0.462	1.161	Poor
41	AO	985	17.5	17238	980	0.192	0.422	-0.321	Poor
42	AP	885	18.5	16373	880	0.471	0.527	1.251	Good
43	AQ	1235	10.2	12597	1180	0.580	1.247	0.645	Poor
44	AR	795	20.1	15980	780	0.261	0.337	0.699	Good
45	AS	587	26.5	15556	540	0.157	0.377	1.107	Good
46	AT	557	31.2	17378	540	0.147	0.273	1.065	Good
47	AU	750	22.2	16650	720	0.266	0.009	0.936	Poor
48	AV	899	18.6	16721	880	0.400	2.010	0.942	Poor

Table 2 (continued)

Exper. no.	Tempered martensite area (%)	Hole enlargement rate (%)	Plating adhesion	Plating appearance	Class
1	<5%	80	Very good	Very good	Comp. ex.
2	<5%	77	Very good	Very good	Comp. ex.
3	<5%	73	Good	Very good	Comp. ex.
4	<5%	70	Very good	Very good	Comp. ex.
5	<5%	66	Very good	Very good	Comp. ex.
6	<5%	65	Good	Very good	Comp. ex.
7	<5%	63	Good	Very good	Comp. ex.
8	<5%	61	Very good	Very good	Comp. ex.
9	<5%	60	Good	Good	Comp. ex.
10	<5%	62	Good	Good	Comp. ex.
11	<5%	58	Good	Very good	Comp. ex.
12	<5%	60	Very good	Very good	Comp. ex.
13	<5%	58	Very good	Very good	Comp. ex.
14	<5%	56	Very good	Very good	Comp. ex.
15	<5%	55	Very good	Very good	Comp. ex.
16	<5%	54	Good	Very good	Comp. ex.
17	<5%	53	Very good	Very good	Comp. ex.
18	<5%	51	Good	Very good	Comp. ex.
19	<5%	50	Very good	Very good	Comp. ex.
20	<5%	49	Very good	Very good	Comp. ex.
21	<5%	44	Good	Very good	Comp. ex.
22	<5%	47	Good	Very good	Comp. ex.
23	<5%	46	Good	Very good	Comp. ex.
24	<5%	45	Good	Very good	Comp. ex.
25	<5%	38	Good	Good	Comp. ex.
26	<5%	37	Good	Good	Comp. ex.
27	<5%	48	Good	Good	Comp. ex.
28	<5%	39	Good	Good	Comp. ex.
29	<5%	41	Very good	Very good	Comp. ex.
30	<5%	40	Good	Good	Comp. ex.
31	<5%	37	Good	Good	Comp. ex.
32	<5%	35	Good	Good	Comp. ex.
33	<5%	54	Good	Good	Comp. ex.
34	<5%	52	Good	Good	Comp. ex.
35	<5%	41	Good	Good	Comp. ex.
36	<5%	35	Good	Good	Comp. ex.
37	<5%	34	Good	Good	Comp. ex.
38	<5%	33	Good	Good	Comp. ex.
39	<5%	64	Good	Good	Comp. ex.
40	<5%	27	Good	Very good	Comp. ex.
41	<5%	47	Fair	Fair	Comp. ex.
42	<5%	45	Very good	Very good	Comp. ex.
43	<5%	30	Fair	Fair	Comp. ex.
44	<5%	50	Good	Good	Comp. ex.
45	<5%	56	Good	Very good	Comp. ex.
46	<5%	60	Good	Very good	Comp. ex.
47	<5%	50	Good	Good	Comp. ex.
48	<5%	49	Poor	Poor	Comp. ex.

Table 3/Method of Production (2)

Exper. no.	Steel type	TS (MPa)	EL (%)	TSxEL	(A) equation				(A) equation judgment
					TS target value (*) (MPa)	(A) equation left side	A1	(A) equation right side	
1	A	376	48.1	18087	360	0.028	0.033	1.194	Good
2	B	379	48.3	18325	360	0.042	0.050	1.257	Good
3	C	443	42.4	18791	440	0.043	0.810	0.972	Good
4	D	467	40.2	18798	460	0.103	0.990	1.164	Good
5	E	501	36.3	18201	500	0.163	0.430	1.278	Good
6	F	511	37.1	18928	510	0.100	0.950	0.969	Good
7	G	523	35.4	18512	520	0.102	0.930	0.942	Good
8	H	530	35.1	18584	530	0.170	0.300	1.200	Good
9	I	550	34.6	19022	540	0.129	0.970	0.987	Good
10	J	537	34.0	18272	530	0.128	0.900	1.020	Good
11	K	551	32.9	18108	550	0.120	0.550	0.912	Good
12	L	594	33.7	20028	590	0.227	1.140	1.233	Good
13	M	633	31.3	19801	630	0.266	1.050	1.257	Good
14	N	653	29.9	19547	650	0.300	0.500	1.335	Good
15	O	706	27.8	19606	700	0.370	0.810	1.461	Good
16	P	747	25.3	18891	740	0.328	0.730	1.134	Good
17	Q	767	25.1	19243	760	0.371	0.870	1.248	Good
18	R	809	24.1	19490	800	0.360	1.000	1.056	Good
19	S	860	22.3	19182	860	0.479	1.110	1.359	Good
20	T	863	23.2	19992	860	0.483	0.780	1.374	Good
21	U	895	21.1	18873	890	0.484	0.580	1.272	Good
22	V	897	22.4	20107	890	0.457	0.850	1.152	Good
23	W	928	21.2	19670	920	0.477	0.680	1.134	Good
24	X	922	20.2	18618	920	0.488	0.880	1.179	Good
25	Y	1228	16.8	20669	1220	0.704	0.780	1.041	Good
26	Z	1274	15.5	19779	1260	0.721	0.850	0.972	Good
27	AA	907	22.1	20037	890	0.347	0.650	0.675	Good
28	AB	1134	16.9	19127	1120	0.646	0.720	1.146	Good
29	AC	1132	17.9	20204	1120	0.653	0.880	1.179	Good
30	AD	1147	17.6	20178	1140	0.537	0.600	0.603	Good
31	AE	1296	14.9	19274	1290	0.707	0.750	0.801	Good
32	AF	1429	13.5	19349	1420	0.847	0.910	0.942	Good
33	AG	731	25.4	18596	730	0.234	0.892	0.759	Poor
34	AH	751	24.0	18044	740	0.257	1.712	0.822	Poor
35	AI	1077	17.4	18701	1070	0.495	0.815	0.672	Poor
36	AJ	1402	13.8	19331	1400	0.759	1.391	0.633	Poor
37	AK	1457	12.7	18440	1450	0.728	0.212	0.315	Poor
38	AL	1459	12.5	18297	1450	0.637	0.106	-0.078	Poor
39	AM	312	37.2	11585	300	-0.091	1.778	0.894	Poor
40	AN	1493	8.5	12695	1490	0.955	0.462	1.161	Poor
41	AO	896	19.3	17255	890	0.118	0.422	-0.321	Poor
42	AP	823	20.7	17054	820	0.421	0.527	1.251	Good
43	AQ	1136	11.1	12632	1120	0.530	1.247	0.645	Poor
44	AR	723	22.1	15995	720	0.212	0.337	0.699	Good
45	AS	546	29.7	16203	540	0.157	0.377	1.107	Good
46	AT	512	34.0	17427	510	0.122	0.273	1.065	Good
47	AU	683	24.4	16667	680	0.233	0.009	0.936	Poor
48	AV	809	20.3	16404	800	0.334	2.010	0.942	Poor

*: Corrected TS target value considering tempering

Table 3 (continued)

Exper. no.	Tempered martensite area (%)	Hole enlargement rate (%)	Plating adhesion	Plating appearance	Class
1	5.2	94	Very good	Very good	Inv. ex.
2	5.3	91	Very good	Very good	Inv. ex.
3	6.4	86	Good	Very good	Inv. ex.
4	6.7	82	Very good	Very good	Inv. ex.
5	7.8	77	Very good	Very good	Inv. ex.
6	9.0	76	Good	Very good	Inv. ex.
7	9.7	74	Good	Very good	Inv. ex.
8	11.4	72	Very good	Very good	Inv. ex.
9	14.6	71	Good	Good	Inv. ex.
10	13.5	72	Good	Good	Inv. ex.
11	17.2	68	Good	Very good	Inv. ex.
12	20.3	71	Very good	Very good	Inv. ex.
13	21.1	67	Very good	Very good	Inv. ex.
14	21.5	66	Very good	Very good	Inv. ex.
15	22.3	65	Very good	Very good	Inv. ex.
16	24.6	63	Good	Very good	Inv. ex.
17	21.1	61	Very good	Very good	Inv. ex.
18	21.6	60	Good	Very good	Inv. ex.
19	22.8	59	Very good	Very good	Inv. ex.
20	24.3	58	Very good	Very good	Inv. ex.
21	25.2	52	Good	Very good	Inv. ex.
22	25.0	56	Good	Very good	Inv. ex.
23	26.2	55	Good	Very good	Inv. ex.
24	25.9	54	Good	Very good	Inv. ex.
25	42.7	45	Good	Good	Inv. ex.
26	45.5	45	Good	Good	Inv. ex.
27	22.3	57	Good	Good	Inv. ex.
28	26.9	46	Good	Good	Inv. ex.
29	26.7	49	Very good	Very good	Inv. ex.
30	43.0	47	Good	Good	Inv. ex.
31	47.6	45	Good	Good	Inv. ex.
32	50.4	41	Good	Good	Inv. ex.
33	20.9	64	Good	Good	Inv. ex.
34	22.5	62	Good	Good	Inv. ex.
35	47.6	49	Good	Good	Inv. ex.
36	55.3	42	Good	Good	Inv. ex.
37	58.7	40	Good	Good	Inv. ex.
38	59.5	40	Good	Good	Inv. ex.
39	<5%	75	Good	Good	Comp. ex.
40	65.3	36	Good	Very good	Comp. ex.
41	31.2	57	Fair	Fair	Comp. ex.
42	25.1	54	Very good	Very good	Comp. ex.
43	38.0	37	Fair	Fair	Comp. ex.
44	21.4	59	Good	Good	Comp. ex.
45	12.1	66	Good	Very good	Comp. ex.
46	8.5	71	Good	Very good	Comp. ex.
47	22.2	59	Good	Good	Comp. ex.
48	22.4	57	Poor	Poor	Comp. ex.

As will be understood from Example 1, the invention examples described in Table 3 are increased in amount of tempered martensite over the comparative examples of the same experiment numbers described in Table 2 and therefore are improved in hole enlargement ability. Further, when equation 1 is not satisfied, while the passing condition is satisfied, compared with steel types with the same degree of TS, the elongation is poor and,

as a result, the TSxEI tends to fall.

Example 2

Steel slabs obtained by melting and casting the steels of L, AA, and AJ of the range of ingredients of the present invention described in Table 1 were reheated to 1200°C, then hot rolled at a temperature of 880°C for final rolling to obtain hot rolled steel sheets. The steel sheets were cooled and held at a temperature of 600°C for 1 hour to reproduce coiling heat treatment. The obtained hot rolled steel sheets were descaled by grinding and cold rolled by a reduction rate of 70%, then preplated and pickled under the conditions of the following experiments 1) to 5):

Experiment 1 (invention example): pickling by 5% hydrochloric acid, Ni pre-plating to 0.5 g/m²

Experiment 2 (invention example): no pickling, Ni pre-plating to 0.5 g/m²

Experiment 3 (comparative example): pickling by 5% hydrochloric acid, Ni pre-plating to 0.005 g/m²

Experiment 4 (comparative example): pickling by 5% hydrochloric acid, no Ni pre-plating

Experiment 5 (invention example): no pickling, no Ni pre-plating

After this, a continuous annealing simulator was used for annealing at 800°C in temperature for 100 seconds, then the sheets were cooled at a 5°C/s cooling rate to 650°C, then were hot dip galvanized at 460°C and alloyed at 520°C in temperature, then were cooled at a 10°C/s cooling rate to the martensite transformation point or less, then were heated at 300°C in temperature for 60 seconds, then were cooled at a 20°C/s cooling rate to ordinary temperature. After this, the sheets were rolled by skin pass rolling by a reduction rate of 1%. The results are shown in Table 4.

Table 4/Differences in Pickling and Preplating Conditions

Experiment number	Steel type	Plating adhesion	Plating appearance	Class
1	L	Very good	Very good	Inv. ex.
2	L	Very good	Very good	Inv. ex.
3	L	Fair	Poor	Comp. ex.
4	L	Poor	Poor	Comp. ex.
5	L	Very good	Very good	Inv. ex.
1	AA	Very good	Very good	Inv. ex.
2	AA	Very good	Good	Inv. ex.
3	AA	Poor	Poor	Comp. ex.
4	AA	Poor	Poor	Comp. ex.
5	AA	Good	Good	Inv. ex.
1	AJ	Very good	Very good	Inv. ex.
2	AJ	Very good	Good	Inv. ex.
3	AJ	Poor	Poor	Comp. ex.
4	AJ	Poor	Poor	Comp. ex.
5	AJ	Good	Good	Inv. ex.

As will be understood from Example 2, from the differences in pickling and preplating conditions, it is learned from experiment 1) and experiment 2) that preplating results in a great improvement in the plating adhesion and plating appearance and further that pickling before preplating is preferable. Further, it is learned from experiment 3) that there is no effect if the amount of preplating is small and, further, from experiment 4), that with just pickling, the results conversely are worse. In the case of only pickling, it is believed that the plating adhesion and the plating appearance conversely deteriorate since the surface is heated in the continuous hot dip galvanization step while overly activated, so Si, Mn, and other oxides of the steel sheet again are formed on the surface of the steel sheet and degrade the plateability.

INDUSTRIAL APPLICABILITY

According to the present invention, it becomes possible to provide a hot dip galvanized composite high strength steel sheet excellent in shapeability and hole enlargement ability for use for automobile parts etc.